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A Technical Progress Report, 1957-58

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RELATION OF DRYING AIR TEMPERATURE, TIME, AND AIR FLOW RATE TO THE NUTRITIVE VALUE OF FIELD-SHELLED CORN

A Technical Progress Report, 1957-58[1]

C. A. Cabell, R. E. Davis,[2] and R. A. Saul[3]

Early harvesting of corn made possible by mechanical drying has improved the efficiency of farm management by increasing yields while decreasing the labor required. Corn can be handled and dried as ear corn but further reduction in storage and handling cost can be effected by shelling the corn in the field either with a picker-sheller or a grain combine with a corn picker attachment. Early harvest at high moisture levels with mechanical drying has introduced new variables with unknown effects on nutritive, storage, and market values. Mechanical drying of corn with either heated or unheated air raises questions relative to establishing the interactions of drying temperature, air flow rates, and harvesting moisture level on the quality of the corn produced. Pinches (9)[4] has discussed the complex nature of the new harvesting methods including the reasons for unusual current interest and involvement of many industries.

It is obvious that some of the questions arising from the situation can be answered only by nutritional experiments to estimate effects of these harvesting variables on feeding value of the corn. The plan of the work reported here was to prepare samples of field-shelled corn while controlling the treatment variables over practical ranges; then to test nutritional values of the samples with rat feeding experiments.

Previous work in this laboratory (4, 5, 6) has shown some of the effects of temperature, moisture, and storage on nutritive value and chemical composition of artificially dried and stored corn.

Results of many experiments to determine possible nutritional losses including vitamins, energy, and protein nutritive value, indicated that this latter factor was the most sensitive to heat. Furthermore, high moisture content resulted in increased losses due to drying with heat. These previous experiments also showed that although significant losses in vitamin content did not occur at temperatures up to 190° F., some reduction at high temperature (300° F.) was indicated in some of the vitamins. It was found that possibly the most significant loss was noted in carotene. Another test that has been suggested as a possible estimate of deterioration in corn is fat acidity value. Therefore it was decided to obtain data for this study of field-shelled corn on carotene and fat acidity in selected samples which had received the extreme treatments and to concentrate on study of protein nutritive values on all the available samples.

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4/ Figures in parentheses refer to Literature Cited at end of this report.

Materials and Methods

Corn samples: Twenty-four 10 lb. dried samples packed in polyethelene lined cloth bags were received at the U. S. Department of Agriculture, Agricultural Research Center, Beltsville, from the field station of the Agricultural Engineering Division, Ames, Iowa in February, 1957. They were stored immediately at 30° F. and portions taken from time to time for the various tests described herein. These samples of corn harvested in 1956 were obtained from two methods of mechanical drying: heated air batch drying and unheated air in storage drying. There were 12 samples representing each method. All of the grain used for the heated air drying was stored at 25 percent moisture in the deep freeze from harvest time in the fall until it was dried in January. The air dried sample was removed from the freezer and dried by exposing it in a thin layer on a table top in the laboratory. The field-dried sample is from the same field of corn but was harvested in January, 1957, after it had dried to 15 percent moisture.

The heated air dried samples were treated in a batch drier of 1.24 square feet cross section filled with sufficient wet corn to yield 1 bushel after drying, that is, to an approximate depth of 13 inches. Except for tests C-3R and C-11, the samples represent the total depth of corn. Samples A, B, and C, from tests C-3R and C-11 represent the bottom, center, and top 2-inch layers of the batch. For test C-18 a vertical auger was placed in the center of the bin which effected a complete recirculation of the corn every 3 to 5 minutes during drying. A detailed temperature history was kept on the C-3R and C-11 samples for the 3 to 4 hour period these samples were treated. Figure 1 shows a schematic diagram of the heated air batch drier used in preparing the heated samples. Figures 2 and 3 show the temperature history of samples C-3R and C-11.

Failure of the heated samples to yield statistically significant differences when tested resulted in preparation of 15 more samples in which a greater range of temperature was used. The samples were prepared from corn field-shelled in the fall of 1957 at approximately 30 percent moisture and stored in the deep freeze until they were dried in December, 1957. These samples of field-shelled corn were dried with air heated from approximately 130° to 300° F., and they represent grain reaching temperatures ranging from approximately 60° to 265° F. Detailed temperature histories are shown in figures 4 to 8. Table I shows other data available on all of the 39 corn samples which were used in this study of field-shelled corn.

Rat feeding tests. The number of samples available made it practical to divide them into groups for assay purposes. They were thus divided into 5 groups of 8 samples each. The groups were arranged so as to obtain desirable comparisons of the treatment variables. Each of the 5 groups was assayed for protein nutritive value by two rat feeding methods, namely, growth of weanling animals and a rat repletion method.

Rat growth assays. Weanling male and female albino rats were allotted to outcome groups of 8 animals each. The groups were equalized as nearly as possible as to weight, sex, age, and genetic origin. Eight such groups were

Table I. Data showing treatment of corn samples[a]

Sample No.	Initial moisture	Moisture after cooling	Air flow rate	Air temp. entering	Protein N x 6.25	Position of sample in drier
	%	%	cfm/bu.	F.°	%	
			Samples dried by heated air			
C-3R-A	25.0	18.0	46.9	186	7.76	Top
C-3R-B	25.0	14.0	46.9	186	7.56	Center
C-3R-C	25.0	13.6	46.9	186	8.16	Bottom
C-11-A	25.0	17.0	84.9	130	7.99	Top
C-11-B	25.0	14.9	84.9	130	7.40	Center
C-11-C	25.0	14.3	84.9	130	7.74	Bottom
C-3	25.5	13.0	50.6	177	7.50	Composite
C-13	25.6	12.8	80.5	197	7.66	Composite
C-17	26.0	12.9	80.8	184	8.02	Composite
C-18	25.5	13.8	94.3	181	7.59	Composite
Air dried	25.0	----	----	---	7.96	Composite
Field dried	15.0	----	----	---	7.59	Composite
1a top	32	--	110	280	9.69	Top
1a middle	32	--	110	280	9.88	Center
1a bottom	32	--	110	280	9.75	Bottom
2a top	29	--	112	239	9.50	Top
2a middle	29	--	112	239	9.88	Center
2a bottom	29	--	112	239	9.88	Bottom
3a top	30	--	50	283	9.56	Top
3a middle	30	--	50	283	9.81	Center
3a bottom	30	--	50	283	10.50	Bottom
4a top	29	--	112	132	9.75	Top
4a middle	29	--	112	132	9.81	Center
4a bottom	29	--	112	132	9.81	Bottom
5a top	29	--	50	126	10.37	Top
5a middle	29	--	50	126	10.13	Center
5a bottom	29	--	50	126	9.88	Bottom
			Samples dried with unheated air			
1	22	13.7	0.88	---	9.86	Top
2	22	14.1	1.5	---	9.96	Top
3	22	14.6	2.5	---	9.88	Top
4	22	15.8	3.0	---	9.94	Top
5	25	14.4	1.0	---	9.96	Top
6	25	13.6	2.1	---	10.02	Top
7	25	13.2	4.5	---	9.93	Top
8	25	14.5	6.7	---	9.88	Top
9	28	16.1	0.85	---	10.40	Top
10	28	14.4	1.9	---	10.46	Top
11	28	14.4	4.7	---	10.25	Top
12	28	15.7	9.1	---	10.20	Top

a/ Sample represents layer of the batch being ventilated at the specified air flow rate - cfm/bu.

randomly assigned to diets prepared from different corn samples. Thus each assay group was a randomized complete block design with 8 replications. In the first assay group, 8 corn samples were compared by feeding diets prepared with corn as the sole source of protein at a restricted level of 8 percent. Previous results with this diet had shown that more uniform growth could be obtained if some of the known inherent deficiencies, viz. lysine and tryptophan, of corn were replaced. It was appreciated that lysine is probably the most susceptible of the amino acids to heat but it was felt that differences due to heat damage would be detected. Also, in the repletion studies no supplementary amino acids were used.

Since no significant differences were observed between the set of corn samples in the first assay, dietary protein level was increased in the other growth assays to 10 percent by addition of soybean meal in the hope that precision could be increased. The diets used in all the growth assays are shown in Table II.

Rat repletion assay. The method and type of animals used in the repletion assays have been described previously (2, 3). In this method the animals were depleted on a low protein diet containing 3 percent of yeast and 0.01 percent of iodinated casein. However, during the repletion period when the corn protein was being assayed as a separate supplement, the yeast and casein were removed from the basal diet. Thus the only source of protein fed during the assay period was the corn sample being tested. The corn supplements were fed daily for a period of 10 days at the maximum level at which complete consumption would be assured. Previous experiments had shown this to be an amount of corn equivalent to 120 mg. of nitrogen per day.

Carotene content of some of the corn samples was determined by a modified "phasic" method and fat acidity by a rapid standard method (1).

Results

Preparation of the corn samples was directed along practical lines and no extreme treatments were used in the processing of the heated air samples from the 1956 corn. Therefore, it is not surprising that little damage to nutritive value was observed in these first samples. As is usually the case in protein nutritive value studies there was considerable variation between individual test animals with both methods of assay. The mean values listed in Table III show differences, but statistical studies indicate that these differences in the 1956 heated samples are not significant at the 5 percent level. As shown in Table III, the only assay group among the first three which had a significant F value was the repletion assay of group 2. Attention should be called here to the fact that all of the mean weights in this group were relatively low as compared to repletion weights in the other two groups. However, since casein was fed as a standard in all of the tests, comparisons between values in different groups should be estimated only in terms of percentage of the casein standard.

The calculated LSD values listed in Table III give some indication of the variation within the treatment groups but since the F values are significant only in one group among the first three, true differences are

Table II. Growth assay diets

	Assay group 1 %	Assay group 2,3,4 & 5 %
Corn	a/	a/
Dextrinized starch	a/	a/
Soybean meal	-	4.5
Mineral mix No. 12 b/	2.5	2.5
Calcium carbonate	.7	.7
l-lysine hydrochloride	.25	.25
Tryptophan	.10	.10
Choline	.10	.10
Vitamin mix c/	.01	.01

a/ Starch and corn varied so as to provide a level of 8 or 10% protein in diet.

b/ Salt mixture No. 12 of Jones and Foster (7).

c/ The vitamin mix included the following in amounts to meet rat requirements, thiamin, riboflavin, pyridoxine, calcium pantothenate, vitamin A acetate, vitamin D, vitamin B_{12}.

Table III. Protein nutritive value and carotene content of corn samples

Assay group	Sample no.	Max. temp.	Growth assay[a] 28 day wt. gain	P.E.[b]	Repletion assay 10-day wt. gain	Carotene Dup. 1	Carotene Dup. 2
		F°	g.		g.	mcg./g.	
No. 1	C3R-A	110	48.5	2.38	16.8		
	C3R-C	193	51.8	2.54	19.3	2.98	2.84
	C11-A	108	49.4	2.28	19.9		
	C11-C	126	63.1	2.60	18.3		
	5		55.8	2.35	17.6		
	6		50.2	2.31	16.5	3.91	3.40
	7		45.4	2.23	17.6		
	8		43.0	2.14	19.1		
	Casein				20.1		
	LSD .05[c]		12.3		2.4		
	Observed F		1.04		1.20		
No. 2	1		98.3	3.03	9.8	4.03	4.24
	2		95.1	2.87	13.1		
	3		108.8	3.15	11.3		
	4		98.9	2.98	9.8	4.42	4.67
	9		76.8	2.64	5.0	3.81	3.86
	10		90.8	2.81	10.8		
	11		99.0	2.93	12.7		
	12		105.8	3.10	12.8	4.19	4.12
	Casein				14.0		
	LSD .05[c]		13.5		2.8		
	Observed F		2.00		3.70**		
No. 3	C-3	145	105.4	2.68	17.1		
	C-13	165	106.6	2.78	18.3	3.52	3.70
	C-17	170	92.8	2.41	16.3		
	C-18	140	110.5	2.80	16.3		
	C11-B	119	107.3	2.70	15.0	3.67	3.62
	C3R-B	152	108.0	2.62	16.4		
	Air dried		116.1	2.76	16.3		
	Field dried		108.8	2.78	14.1		
	Casein				19.7		
	LSD .05[c]		9.0		3.3		
	Observed F		2.09		1.00		
No. 4	2a middle	205	105.6	2.84	19.5	3.24	2.98
	3a top	105	108.0	2.93	19.1	3.05	3.12
	3a middle	235	81.3	2.43	15.2	2.76	3.05
	3a bottom	265	49.8	1.79	8.8	3.04	3.13
	5a top	83	94.6	2.71	19.3		
	5a middle	90	104.1	2.74	19.5	3.39	3.51
	5a bottom	110	103.3	2.83	20.1		
	Casein				22.9		
	LSD .05[c]		14.0		2.1		
	Observed F		30.03**		9.27**		

(Continued on next page)

Table III (continued). Protein nutritive value and carotene content of corn samples.

Assay group	Sample no.	Max. temp.	Growth assay[a/] 28 day wt. gain	P.E.[b/]	Repletion assay 10-day wt. gain	Carotene Dup. 1	Carotene Dup. 2
		F°	g.		g.	mcg./g.	
	1a top	123	107.3	2.85	20.6		
	1a middle	225	112.4	2.90	19.6	3.30	3.35
No. 5	1a bottom	238	84.3	2.46	16.2		
	2a top	170	106.0	2.84	18.0		
	2a bottom	225	100.3	2.82	19.6		
	4a top	80	111.6	2.92	21.0		
	4a middle	110	102.3	2.79	20.9	3.65	3.83
	4a bottom	118	104.5	2.88	20.6		
	Casein				22.8		
	LSD .05[c/]		11.5		3.4		
	Observed F		2.40*		1.24		

All wt. gain values are expressed as means of 8 animals, 4 males, 4 females in the growth assays and 8 males in the repletion assays.

a/ 8% protein level fed in group 1 growth assay and 10% fed in groups 2 and 3.

b/ Protein efficiency, grams gain per gram of protein eaten.

c/ Least significant mean difference at the 5% level.

* Significant at 5% level.

**Significant at 1% level.

indicated among the mean weights only in the group 2 repletion assay (8). In this group the mean differences in weight gains on samples 9, 10, 11, and 12 harvested at the high level of moisture (28 percent) and dried with unheated air indicate that protein nutritive value varies with rate of air flow during the drying process, and that the low rate of air flow used with sample 9 was below minimum requirements under the conditions of these experiments. There is good agreement between the two assay methods on the low weight gain on sample 9. This sample with the low value of 76.8 for growth and 5.0 for repletion had visible mold growth, and there was some decrease in food consumption indicating palatability was affected. The possibility that toxic mold products may have been involved should not be overlooked. However, it also shows the lowest protein efficiency of the samples in that assay group.

In making other comparisons to observe contrasts of the treatments no differences are evident in the first three groups. For example, a comparison of samples C3R-A and 8 shows some difference in assay but the difference is reversed in the two assay methods, probably indicating no significant differences. Similar results are shown by samples C11-A and C11-C which were samples taken from a different location in the batch and representing different maximum temperatures. Sample C-13, which was treated with entering air at 197° F., showed no measurable damage. Sample C-17 gave a relatively low value by growth assay but the repletion results and statistical studies indicate that this difference is not significant. For the same reasons the relatively high gain of 116.1 for growth assay of the air dried sample in group 3 is not considered significant. The results indicate no true differences between this air dried and field dried sample and those in the first three groups dried by artificial heat.

In the last two assay groups, representing more extreme temperatures, there is definite indication of losses in protein nutritive value as measured by both assay methods. There is good agreement between the methods and high correlation with temperature histories as shown in the charts. Sample 3a taken from the bottom position and heated to 265° F. shows greatest loss in protein nutritive value. Samples 1a, bottom, and 3a, middle, heated to 238 and 235° F., respectively, show less but definite losses. However, samples 1a, middle, and 2a, bottom, heated to 225° F. apparently were undamaged.

All of the five samples heated to 225° F. and above showed brown discoloration and parched corn odor. This was quite marked in the three samples heated to 235° F. and above, and only slight in the two samples heated to 225° F.

Other determinations made on the samples included crude protein on all samples and carotene on selected samples. It was necessary to determine crude protein because the protein nutritive value assays were based on feeding an exact level of nitrogen. Crude protein content, as expected, showed no effects of the treatments. The protein values are included, Table I, because they serve to indicate uniformity of the samples. Results of duplicate determinations of carotene are given for 15 of the corn samples in Table III. Small differences are indicated but there is no evidence that treatment of the corn had much effect on carotene content.

Fat acidity values were determined on some selected samples as follows: 1a top, 24; 2a bottom, 15; 3a middle, 19; 3a bottom, 17; 4a middle, 33; 4a bottom, 30; 5a bottom, 29; 2 unheated, 44; 9 unheated, 106; 10 unheated, 65; 11 unheated, 33; 12 unheated, 31. These values indicate that fat acidity is not increased by the heated air treatments. For example, the value of 17 for the 3a bottom sample is relatively low whereas this sample had a relatively high heat treatment and showed marked loss in protein nutritive value. This would indicate that fat acidity would not be a satisfactory measure of heat damage in corn drying. The high fat acidity value of 106 for sample 9 dried with unheated air is in agreement with the generally known fact that mold growth causes increased fat acidity in grain.

Discussion

In previous reports (5,6) it was shown that artificial drying at temperatures above 135° F. could cause damage to protein nutritive value of corn. However, other variables including moisture content and time of heat treatment were involved. For these previous samples the heating period was 12 hours or more, whereas none of the samples which are the subject of this report were held above room temperatures longer than approximately 4 hours. Reference to the temperature histories, figures 1 to 7, shows that the samples were held at the maximum temperatures only for a short period of time. A study of these charts should reveal to some degree the amount of time it is safe to hold the grain above given temperatures in the drying range.

It appears in these tests that 29 to 32 percent moisture shelled corn can be dried without loss of protein nutritive value with air having temperatures as high as 240° F. provided that the air flow rate is approximately 110 cfm per bushel so that the average moisture of the batch is reduced to safe storage level in about 1 1/2 hours or with air having temperatures up to 180° F. with air flow rates of 50 cfm per bushel so that drying is accomplished in about 3 hours.

Since corn constitutes a high proportion of many animal diets its 8 to 10 percent protein contributes greatly as a protein source; however, it is often considered principally as a source of energy. In a previous report (6) it was shown that a drying temperature of approximately 170° F. for a period of 38 hours, although quite injurious to protein nutritive value, had no effect on corn as a source of dietary energy. This together with the tests reported here indicate that treatment of 29 to 32 percent moisture corn with drying air temperature up to 240° F. for 1 1/2 hours or less will not result in damage to feeding value under at least certain conditions. Since temperature in the grain mass is a function of air flow rate this factor is involved in these conditions. Under the conditions of these tests an air flow rate of 50 cfm/bu and a maximum air temperature of 283° F. resulted in greater damage to corn than an air flow rate of 110 cfm and maximum air temperature of 280° F. In previous work (6) no measurement of air flow rate was maintained, therefore direct comparison of results cannot be made. However, in the tests described herein air flow rate appears to be an important factor in the corn drying process.

Statistical Treatment of Rat Assay Data

Analysis of variance was used in statistical study of the data. Results are summarized in table IV. In the first three assay groups, a significant mean square for treatments at the 5% level is shown only by the repletion assay of group 2. However, significant mean squares for treatments are shown by both methods in group 4 and by the growth method for group 5. Much of the variation in the growth assays is shown to be due to sex except in group 4. Many other assays in this laboratory have shown that at a critical level of protein below 10% that the normally expected greater growth of males was not obtained. This is further indication that protein destruction has taken place in the samples heated to high temperature in this group. Replications or outcome groups did not show significant mean squares in all groups but the mean squares were generally larger than the error terms.

In the first assay group with no supplementary soybean protein the treatment and error variances are about equal. Since in all the other groups the treatment mean squares are significant or near significance at the 5% level the soybean supplementation probably increased precision of the growth assays.

Summary

Data are presented on estimates of the effects of new harvesting methods of field shelling and drying of corn on the nutritive value of the grain. Thirty-nine corn samples were prepared. Both heated and unheated air methods of drying were used. Treatment variables of temperature, time of heating, air flow rate, and harvesting moisture contents were studied.

Drying 25% moisture corn with air heated up to 197° F. for 4 hours or less did not reduce protein nutritive value significantly. Corn with initial moisture of 29 to 32% dried with air heated to 240° F. and air flow rate of 110 to 112 cfm/bu was undamaged in drying. Air temperatures above this, 280° F., caused marked brown discoloration, parched corn odor, and losses in protein nutritive value shown by the rat assay methods. Drying 28 percent moisture corn with unheated air at an air flow rate of 0.85 cfm/bu resulted in mold development and indications of losses in protein nutritive value. Increased air flow or reduced original moisture prevented marked mold development and loss of protein nutritive value in corn dried with unheated air.

A limited number of carotene determinations indicated that the drying treatments caused no significant losses of carotene in the corn samples. Fat acidity was not changed to a marked extent by heated air treatments but was increased significantly when mold growth developed in corn dried by unheated air with a low air flow rate.

Table IV. Summary of analysis of variance of the results of the five protein assay groups by both methods

Source of variation	Degrees of freedom	Assay group No. 1	2	3	4	5
		Mean squares				
		Growth assays				
Total	63					
Treatments (T)	7	309.39	720.46	349.07	11529.43**	627.14*
Sex (S)	1	2525.06**	3540.25**	24063.76**	83.26	2450.25**
O.G.within S	6	496.91	385.53	292.12	212.00	401.29
Outcome groups (OG)	3	690.62	724.90	477.47*	381.26	677.37
S x O.G.	3	101.19	46.17	106.77	42.73	125.21
T x S	7	523.46	760.00	505.73*	404.87	242.29
Error	42	295.13	359.38	166.35	383.80	261.56
		Repletion assays				
Total	71					
Treatments	8	13.93	44.00**	19.04	147.10**	28.41
Replications	7	26.36*	128.08**	14.22	16.89	55.65
Error	56	11.58	11.88	19.31	15.86	22.89

* Significant at 5% level.

**Significant at 1% level.

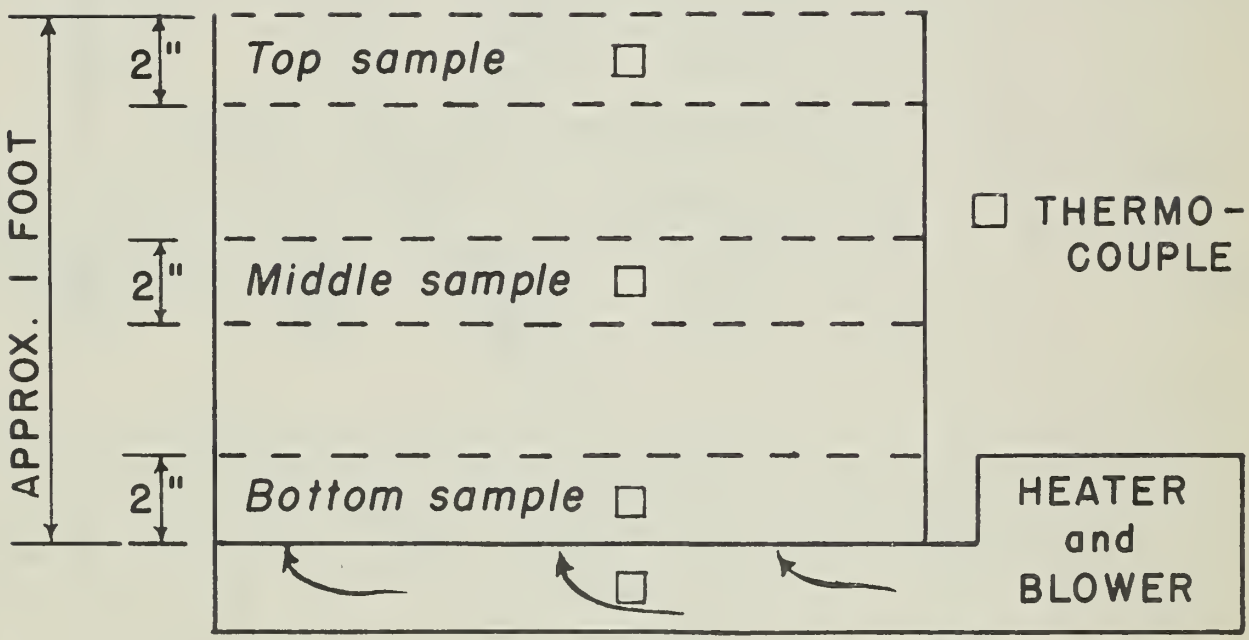

Figure 1. Schematic diagram of heated air batch drier showing relative positions of the samples taken for nutritive studies and the location of thermocouples for measuring temperatures during the drying period.

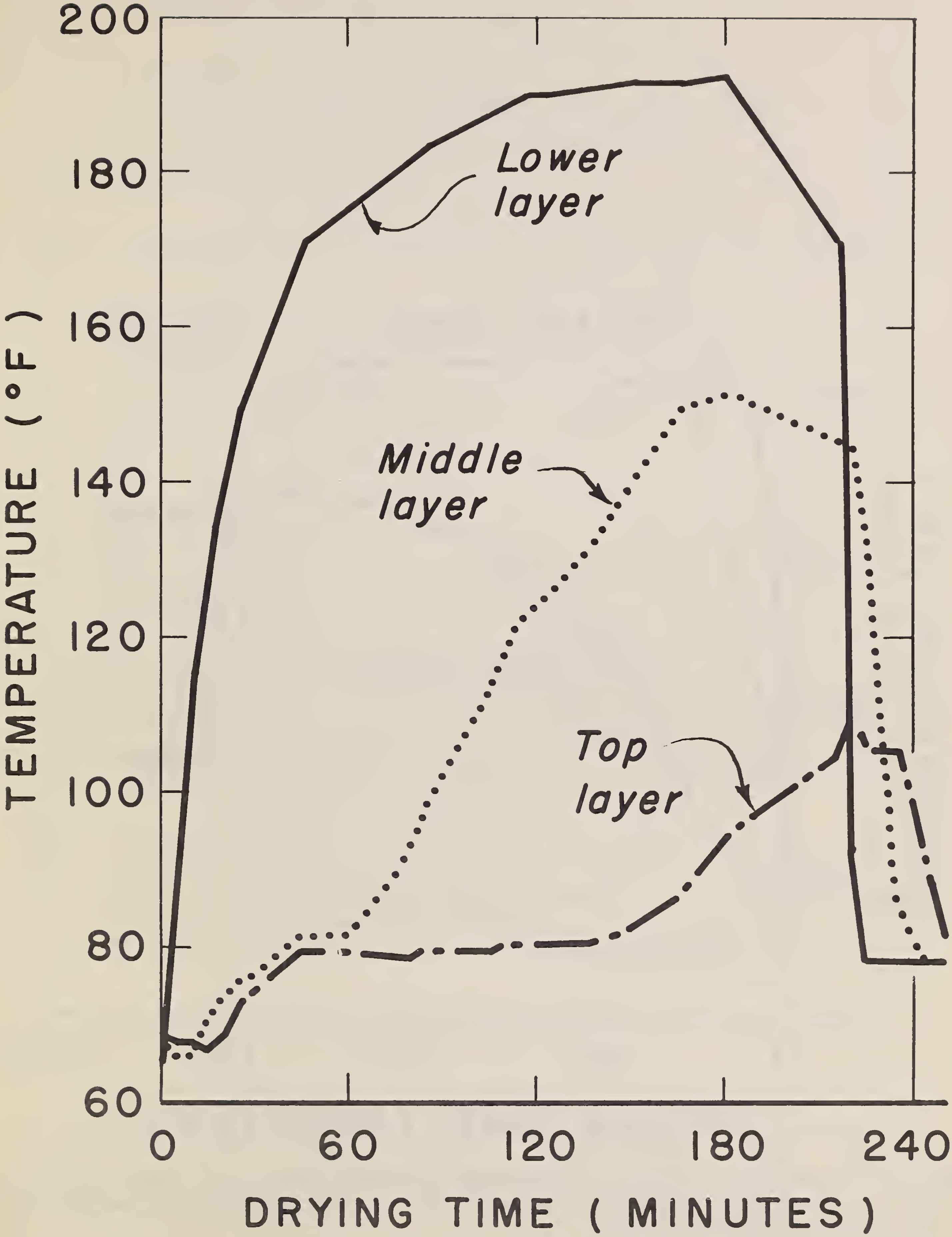

Figure 2. Test C-3R Temperatures measured during drying of field shelled corn from 25% moisture to 15% moisture with air heated to 186° F. flowing at the rate of 47 cfm per bushel.

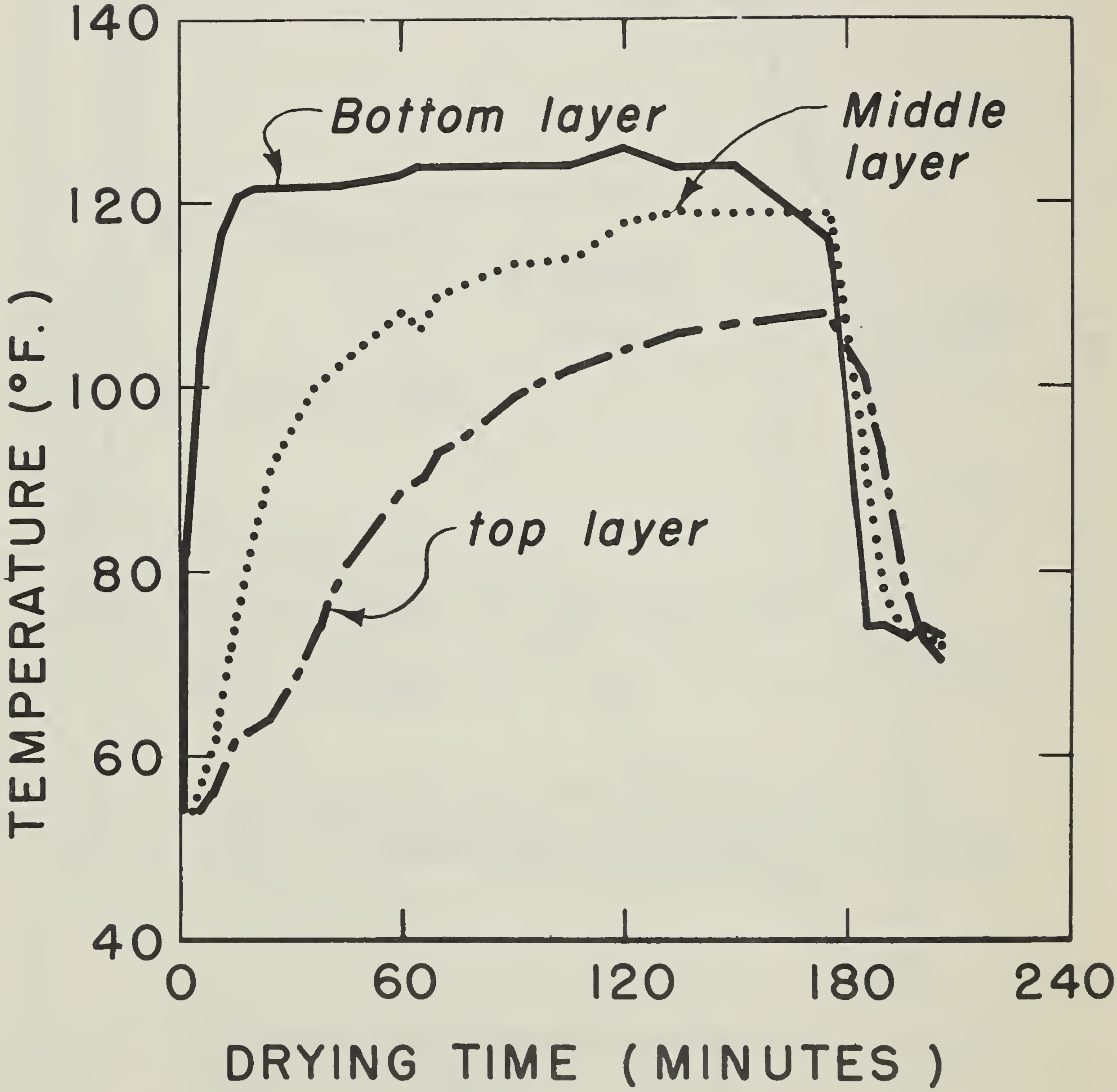

Figure 3. Test C-11 Temperatures measured during drying of field shelled corn from 25% moisture to 15% moisture with air heated to 130° F. flowing at the rate of 85 cfm per bushel.

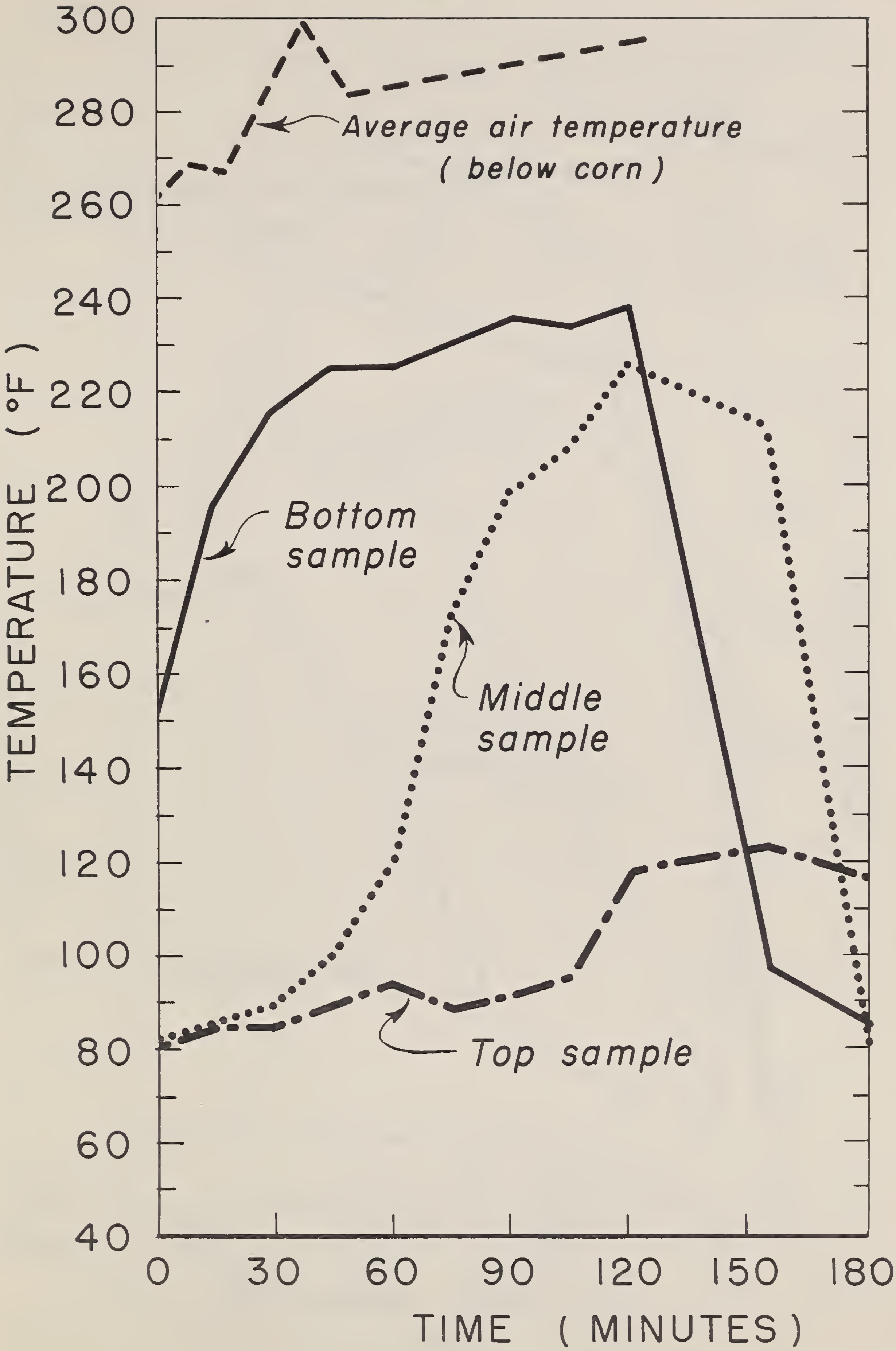

Figure 4. Test 1-a Temperatures measured during drying of field shelled corn from 32% moisture to 11% moisture with air heated to 280° F. flowing at the rate of 110 cfm per bushel.

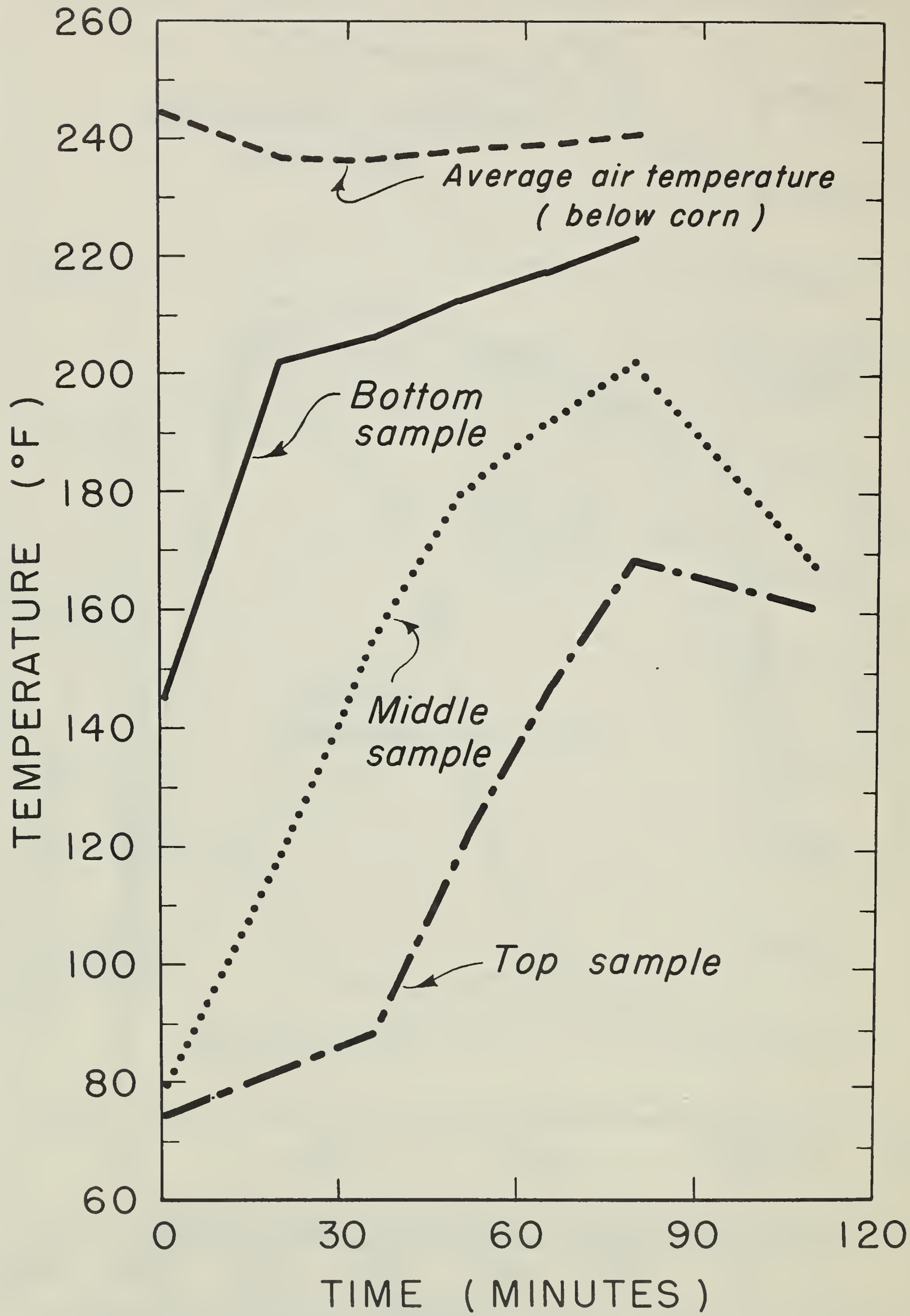

Figure 5. Test 2-a Temperatures measured during drying of field shelled corn from 29% moisture to 11% moisture with air heated to 239° F. flowing at the rate of 112 cfm per bushel.

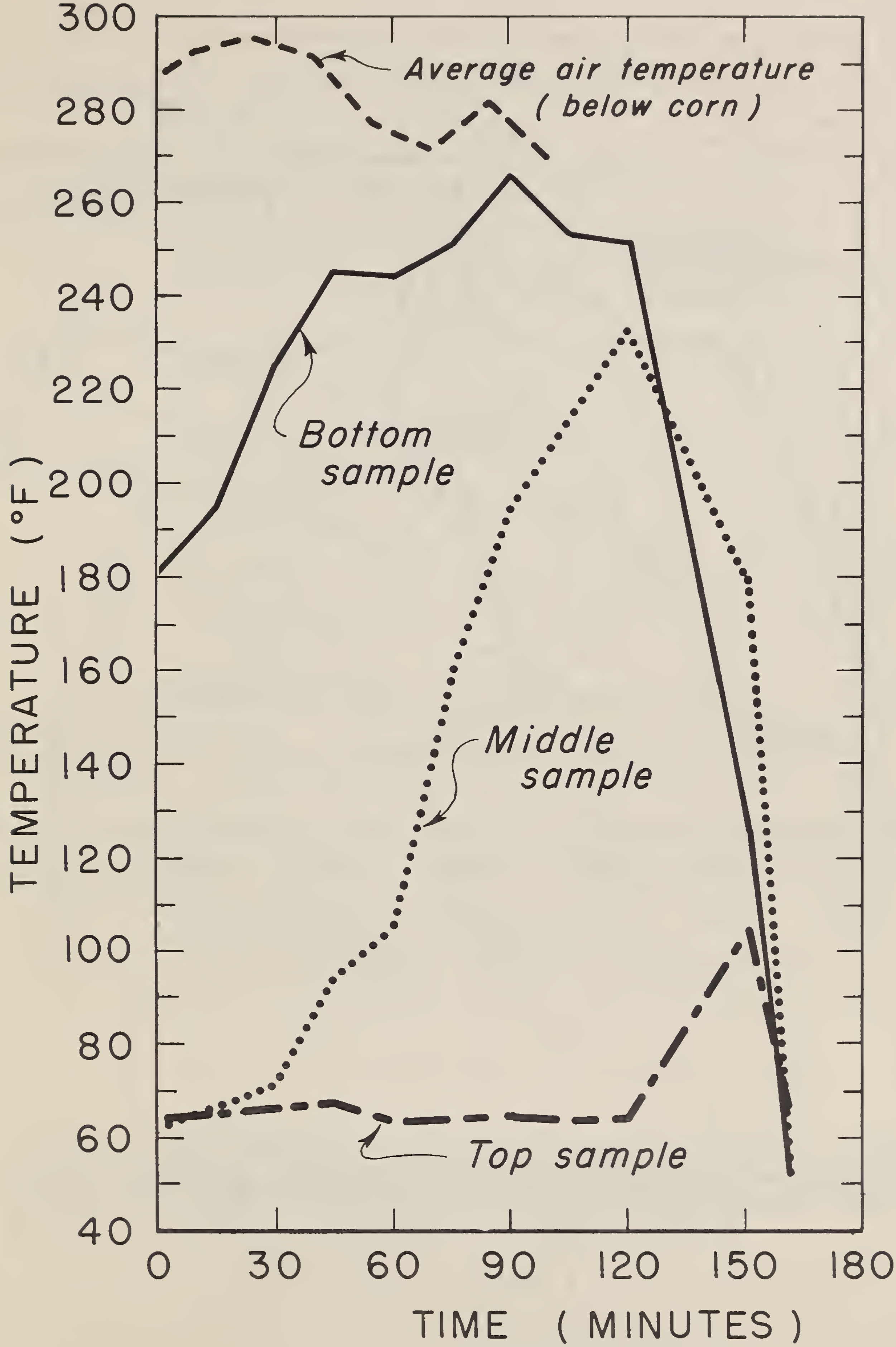

Figure 6. Test 3-a Temperatures measured during drying of field shelled corn from 30% moisture to 13% moisture with air heated to 283° F. flowing at the rate of 50 cfm per bushel.

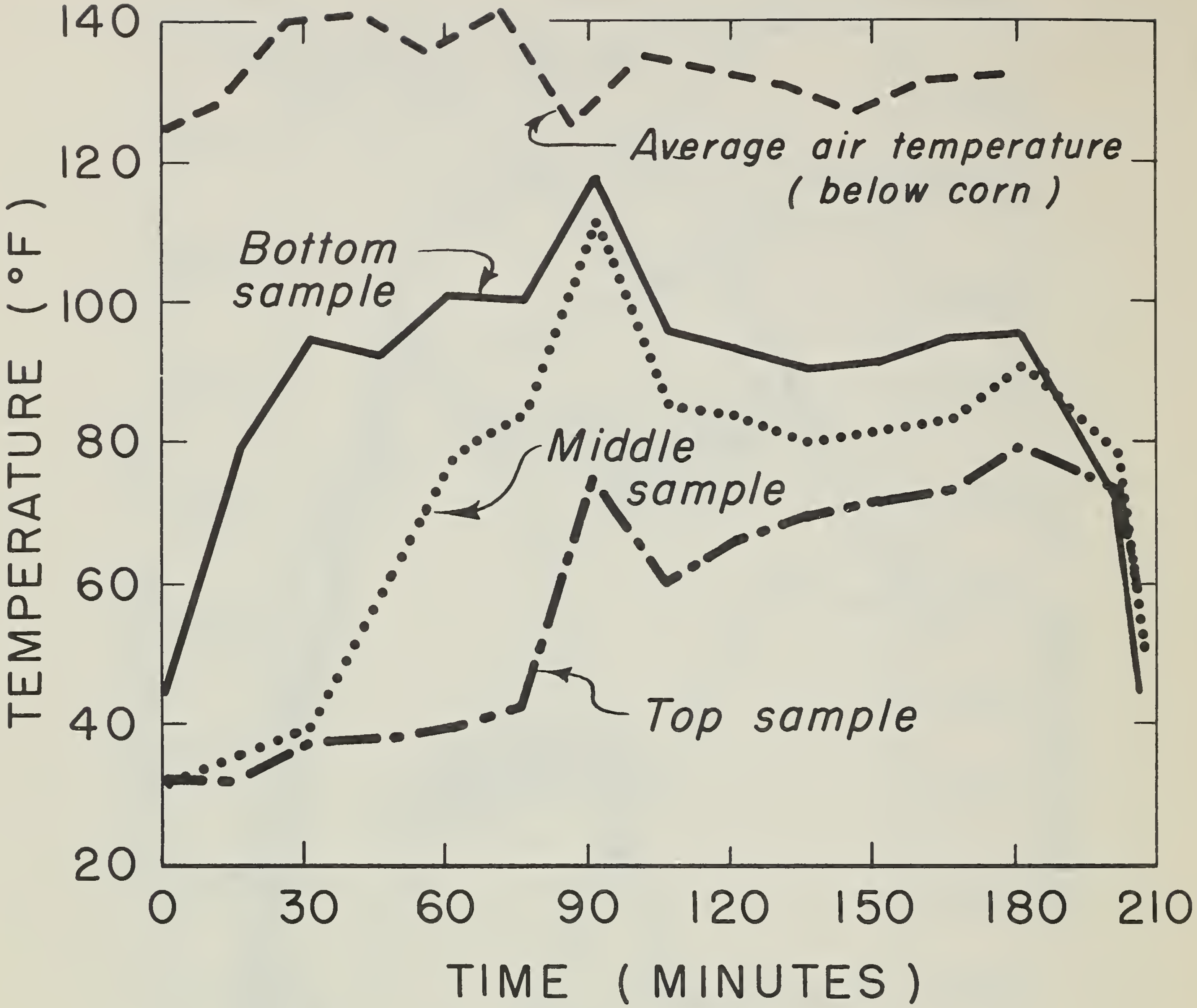

Figure 7. Test 4-a Temperatures measured during drying of field shelled corn from 29% moisture to 16% moisture with air heated to 132° F. at the rate of 112 cfm per bushel.

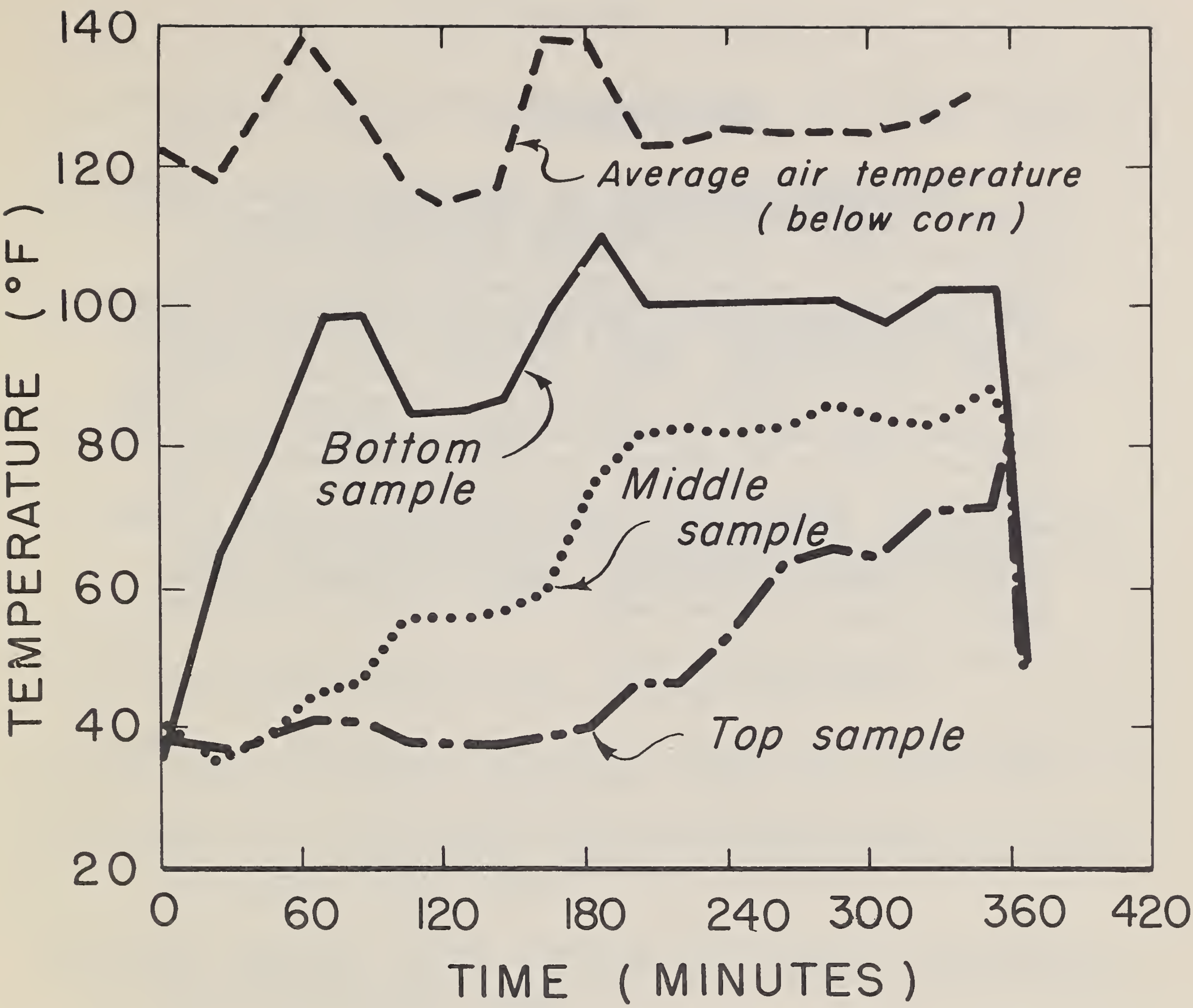

Figure 8. Test 5-a Temperatures measured during drying of field shelled corn from 29% moisture to 13% moisture with air heated to 126° F. flowing at the rate of 50 cfm per bushel.

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